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From Curriculum To Career: Analysing The Contribution Of Delft University's Robotics Msc Programme To The Career Path Of Its Alumni

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FROM CURRICULUM TO CAREER: ANALYSING THE CONTRIBUTION OF DELFT UNIVERSITY'S ROBOTICS MSC PROGRAMME TO THE CAREER PATH OF ITS ALUMNI

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ABSTRACT
The increasing global demand for robotics expertise led the Delft University of Technology to launch a two-year Master of Science programme in Robotics in 2020. The programme was designed to educate versatile robotics engineers capable of overseeing the entire process from conception of robotics systems to implementation. The curriculum integrates disciplines such as machine perception, artificial intelligence, robot planning and control, human-robot interaction, and ethics, and emphasises personal development through a course called Portfolio, which was later rebranded as Vision and Reflection. The effectiveness of the programme was evaluated by conducting a survey among the first cohort of students. The online survey, completed by 21 alumni, assessed the programme's alignment with graduates' career paths and their perceptions of the programme. Most respondents (81%) secured employment, with 69% in robotics, and all others had consciously chosen different fields. On average, graduates found jobs in under a month. Common job titles were Robotics Engineer and Software Engineer. However, graduates least appreciated the original Robot & Society and Portfolio courses. The recently rebranded Vision and Reflection course is expected to improve student engagement by focusing on meaningful reflection rather than documentation. Overall, the programme received positive feedback, with 88% of respondents saying it provided a comprehensive robotics education, and 94% stating they would choose it again. However, the evaluation was limited to the more successful half of the cohort, indicating the need to assess the experiences of the remaining graduates, who took over 2.5 years to complete their degrees.

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1 INTRODUCTION

A new two-year MSc programme in Robotics was launched at Delft University of Technology (TU Delft) in the Netherlands in 2020. It was developed as a collaborative effort among professionals, academia, and students, with the aim of training versatile robotics generalists. In this paper, we describe why and how the programme was developed, and present the resulting curriculum. Having welcomed our third cohort of students in September 2022, we are reflecting on our experiences to date and presenting the results of an online survey conducted with the first graduates.

1.1 Why a Dedicated Robotics Programme?

A 2018 study of the Dutch Robotics Industry (Holland Robotics) valued the worldwide robotics market at €22 billion and was forecasted to increase to €50 to €60 billion by 2020 (Berenschot 2018). The study listed five countries—China, Korea, Japan, the USA, and Germany—that accounted for 75% of global robot sales. Europe as a whole accounted for 32% of the industrial market and 63% of the non-military service market.

At that time, the Netherlands was not a major player; Italy, France, and Spain were the strongest in Europe, after Germany. Hence, in 2018, the Dutch Robotics Industry launched an ambitious plan to expand the sector, fuelled by joint investments from the existing robotics industry and the Dutch government. The report also noted that the number of STEM students in the Netherlands is relatively low and that proficient engineering students often choose to study abroad. Furthermore, the report suggested that a partial cause of this situation is the insufficient emphasis on robotics within the educational system. Around the same time, Dutch universities were working on a sector plan on technology (Sectorplan Betatechniek) at the request of the Dutch government. Within this assessment, similar needs were identified and as a result, TU Delft decided to profile and distinguish itself amongst others in the area of robotics.

The above insights laid the foundation for creating a dedicated MSc Programme in Robotics, housed within the faculty of Mechanical Engineering at TU Delft, where robotics was already a research focal point, led by a Cognitive Robotics department. The faculty also oversees the TU Delft Robotics Institute, a university-wide robotics collaboration. In addition to research collaboration, it has previously developed successful educational robotics programmes such as a minor (30 EC) and an honours programme (15 EC), available to students from various BSc degrees offered at TU Delft.

1.2 Curriculum Design and Philosophy

This programme, unlike most MSc programmes that focus on a specific discipline within robotics, aims to train versatile robot generalists, as mentioned above, training them to be creative and to find solutions from different perspectives. This approach originated from the strategic vision of the host Department of Cognitive Robotics, which posits that future robotics engineers will be responsible for guiding society's transition towards increased robotics. Consequently, it is crucial for robotics engineers to receive education not only in a diverse array of purely technical disciplines (qualification) but also in human-robot interaction as well as societal and ethical aspects.

Additionally, to prepare students for a rapidly changing society, a decision was made to include personal and leadership development as key components of the programme, by teaching students to take responsibility for their professional choices (subjectivation) and being able to think critically across cultural and societal contexts (socialisation). The key components—qualification, subjectivation, and socialisation—are based on the educational framework proposed by Biesta (2021).

The curriculum design process implemented the principle of co-creation (Van den Akker (2007), by involving not only academic staff and learning developers but also alumni and MSc students from mechanical engineering working on robotics-related topics, as well as industry representatives. During this process, the development team first defined the societal challenges in the robotics domain, using the Berenschot report (2018) as a reference. Subsequently, a professional profile of the future robotics engineer was created through consultations with the professional field and discussions with students on their desired learning path, and with alumni about what they felt was lacking when they entered the job market.

Next, the team identified the essential technical and professional learning objectives, from which the final qualifications were formulated. These qualifications served as starting points for the collaborative curriculum design process among staff, students, and learning developers. The resulting curriculum design was then shared with and discussed by external stakeholders, including companies, government, and staff from other universities.

1.3 Professional Profile

A robotics engineer possesses knowledge and expertise at the intersection between mechanical engineering and artificial intelligence (AI), and is capable of creating robotics solutions that can perform tasks in complex environments. The focus of robotics lies in the interaction between machines in human-inhabited environments. Although the profile must be viewed as a dynamic entity due to the continuous and rapid developments within the field of robotics, it was determined that a robotics engineer is involved in: 1) understanding how applications function in practice; 2) translating social issues into intelligent machine solutions in complex, multi-dimensional situations that consider ethics, safety, and sustainability; 3) staying up to date on technical developments in robotics and AI; 4) researching, developing, implementing, and testing AI for mechanical engineering systems to improve learning and interaction with their environment; 5) developing mathematical models (perception models, behavioural models, situation analyses, etc.); 6) conducting physical modelling; 7) programming and developing intelligent software for mechanical engineering systems; 8) advising businesses, government, and society on future choices and steps concerning the use and development of robotics; and 9) managing information from sensors and integrating them into complex robot solutions.

The final qualifications of the programme reflect this professional profile and are also in line with the criteria for engineering degrees in the Netherlands, as defined by Meijer et al. (2005) in their translation of the Dublin Descriptors into the Dutch Engineering Education domain. The final qualifications are listed in Appendix A.

2 ROBOTICS CURRICULUM

Based on the principles and processes described above, the curriculum was designed with four connected didactical goals:

1. To provide students with an understanding of the development of intelligent robots and vehicles that will advance mobility, productivity, and quality of life, firmly rooted in theory and with a focus on applications;

2. To train students in handling the entire process of innovative and sustainable designing, operation, and use of robots, as well as computer systems for their control, sensory feedback, and information processing;
3. To guide students in performing research on robotics topics at an academic level;
4. To teach students to operate in complex and multifunctional environments, assuming various roles and developing transferable skills.

The programme is designed for students with a background in mechanical or aerospace engineering who are interested in further developing their skills in robotics beyond technical knowledge. Its objective is to produce graduates who possess an understanding of the global context in which they operate and the capacity to engage with societal issues both as engineers and citizens (Turns et al 2014 and Niever et al 2020).

2.1 Programme Overview

The resulting two-year 120 EC curriculum, which consists of a mix of lectures, team projects, and individual assignments, is shown in Fig. 1. The programme consists of a number of core courses stacked in the first half of year 1 that provide a solid background in Robotics (qualification – Biesta 2021): Robot Dynamics & Control, Machine Learning for Robotics, Robot Software Practicals, Machine Perception, Planning & Decision Making, and Human Robot Interaction, In addition, the course Robot and Society, focusing on the ethics of technology in general as well as on the ethics of robots and AI, form part of the core programme.

In the second half of Year 1 and the first part of Year 2, students are given more agency over their learning when selecting their electives. Students are given the opportunity to practice their preferred roles in the field of robotics in the context of the Multidisciplinary Project. In this course, students work in self-steering teams of 4–5, designing a functional robot for a real customer (socialisation).

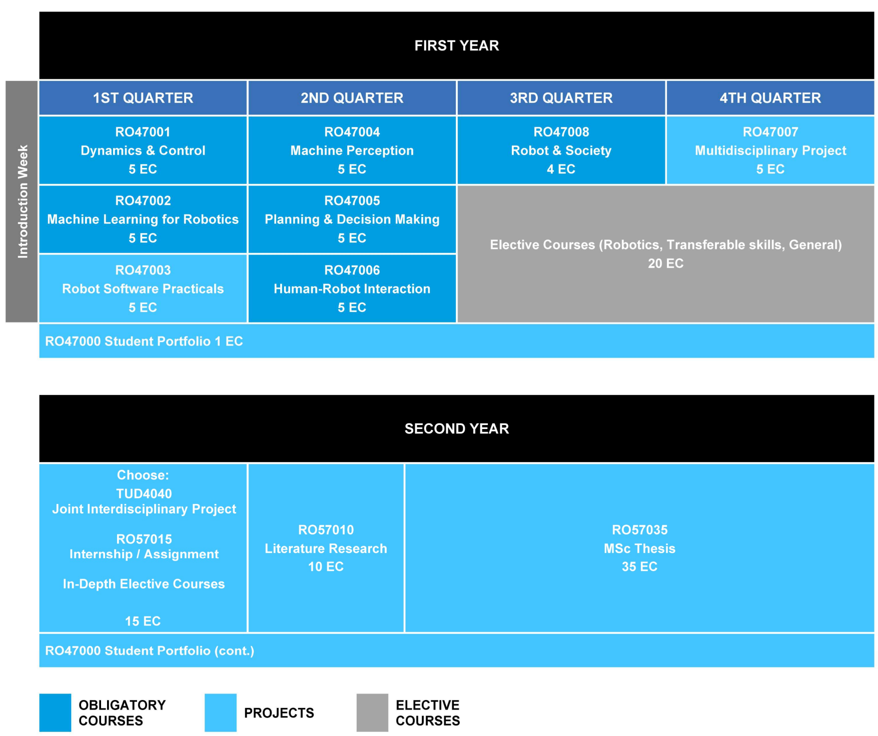

Fig. 1. Programme Overview of the MSc Robotics Programme

Students continue focusing on their individual development and preferences in the first quarter of year 2 by completing a 15-EC internship in a company, an internal research assignment, a joint interdisciplinary project (Klaassen et al 2022), or in-depth courses. The students' choices will depend on their developed vision, which they previously presented in the Vision and Reflection course. In line with that, students continue with a literature study (10 EC) and their final thesis (35 EC) on a topic of their choice.

2.2 Reflective Engineer

To train students in reflection, students practice their reflection skills and learn to set personal development learning goals in the course 'Portfolio', subsequently rebranded as 'Vision and Reflection' alongside the technical courses from the start. This course was developed to facilitate informed decision-making, personal development, and career planning for students pursuing their degrees (subjectivation). Within designated groups, students are guided by experienced mentors creating a safe atmosphere for collaborative learning and examination of the impact of reflection, offering opportunities for students to make and learn from errors.

During this course, students set their own personal development goals and, based on those goals, make choices in the individual part of their curriculum to help them reach those goals. Students have to select at least one relevant elective in the disciplines of humanities and social sciences domain to expose Robotics students to related relevant disciplines and help them develop their desired transferable skills. Examples are courses in logistics, cultural differences, regulations, production processes, sustainability, design, economics/business, or (project) management.

Many of the core courses also include reflective-engineering elements. For example, in the course Machine Learning for Robotics, students collaborate and coordinate with a lab partner on coding and reporting tasks, while in Robot Software Practicals, group work is performed and peer evaluation of coding work is included. In the aforementioned multidisciplinary project, students reflect on their team roles and their robotics specialist roles, and the impact their robot may have on the envisioned customers and society (Van der Niet et al 2023). In addition, based on their personal goals students must select at least one robotics elective; and have the freedom to select the remainder of their elective space for general elective choices, enabling students to immerse themselves in other subjects and further enhance their multidisciplinary profile.

With this combination of active reflection, relevant courses in the field of engineering, humanities, and social sciences (in which transferable skills are both implicitly and explicitly present), and student agency in personal goal setting, this programme is the first engineering MSc programme within TU Delft to exhibit an explicit emphasis on personal leadership development for students.

3 INITIAL EXPERIENCES

The new Robotics MSc was launched in September 2020 with an inaugural cohort of 102 students. Among them, 69 were from BSc programmes at our own university (mainly Mechanical and Aerospace Engineering), 11 from other BSc and BEng programmes in the Netherlands, and 22 from abroad. Enrolment in 2021 increased to 118 students, with a peak in international admissions (31), and in 2022, 90 students began the programme. As of 16 April 2023, 47 out of the 102 students who started have graduated, a success rate of 46%. This is on par with the average for the 2020 cohort within our university as of 1 May 2023, and it exceeds the average of all MSc programmes offered by the Mechanical (35%) and Aerospace Engineering (32%) faculties. This number is indicative that the programme in its first run is already quite well aligned, although higher success rates are aimed for.

3.1 Experiences with Personal Leadership Development

The implementation of reflective engineering involved a learning phase, during which the programme received feedback from students, faculty-level organisations, and other stakeholders. A crucial lesson learned was that ‘reflection’ should engage students in meaningful contemplation, rather than mere documentation or portfolio production. This observation was predominantly based on feedback from students and observations of the course coordinators. Specifically, it appeared challenging to engage students through writing activities (which were often postponed until the last possible moment); on the other hand, presentations in mentor groups and gatherings received positive feedback from both students and mentors, including initially skeptical students.

Consequently, in 2021, the Portfolio course transitioned from group sessions and a portfolio form, to just group sessions while incorporating more student mentors in the form of second-year MSc students. While this change led to some improvements and a reduction in workload, in 2022, the management proceeded further by eliminating all formal deliverables, except for active participation, in accordance with the reflective engineering principles (Hermsen et al 2022). In the renamed course ‘ Vision and Reflection’, PhD students and senior MSc students facilitate reflective sessions in small groups during the first semester of Year 1, enabling students to work toward their personal learning objectives and discover their professional identities.

3.2 Industry Feedback

To maintain alignment with the needs of the robotics field and preserve educational collaborations within the professional domain, the programme management conducts quarterly meetings with the professional advisory board. At the latest meeting, one industry representative remarked that the generic capabilities of robotics graduates serve as a unique selling point, stating, ”*pure programmers get stuck because they do not understand the physics of robotics, and mechanical designers get stuck because they do not understand what the robot does.*” A second representative underscored the breadth of Robotics graduates, making them versatile and broadly employable. A third representative also emphasised the growing necessity for process-oriented thinking in Robotics engineers.

4 ALUMNI RESEARCH

As the first cohort of students graduate and transition into the workforce, it is crucial to assess whether the programme’s goal of producing versatile robotics engineers has been met, by gathering feedback from the initial alumni. Garnering insights from alumni is a well-established method for curriculum evaluation (Saunders-Smits and de Graaff 2012).

4.1 Research Question and Methodology

The primary research questions guiding this investigation included: Did the alumni consciously choose to pursue careers in the robotics field? If so, why ? If not, why not? What insights can be gleaned from alumni feedback and perceptions concerning the MSc Robotics Programme?

Following the acquisition of ethical approval, an online survey was administered on April 19, 2023, to all alumni who had graduated by April 16, 2023, using email or LinkedIn connections maintained by staff members. A follow-up reminder was sent one week later. Out of the 47 graduates, 44 were successfully contacted, and out of them, 21 participated in the survey of which 16 completed the entire survey. This yielded a 45% response rate, which is considered high for online alumni research (Lambert and Miller 2014) and is in line with earlier alumni studies at TU Delft (Saunders-Smits and de Graaff 2012).

4.2 Employment

Out of the 21 respondents, 16 were employed, 1 was employed as a PhD student, and 4 were not employed. Of the first category, 69% (11 out of 16) reported that they are currently working within the field of robotics. Of those not working in robotics, none expressed a desire to do so, citing reasons such as low salary potential and a lack of interest, although 80% (4 out of 5) still retained an occupation within the wider engineering sector. On average, it took respondents less than a month ($M = 0.89$, $SD = 1.20$, $n = 14$) to find a job after they completed their degree. Common job titles include robotics engineer ($n = 4$), software engineer/developer ($n = 5$), as well as data scientist/analysist ($n = 2$). Many alumni are employed in industries that use or produce robots, or engage in robotics and AI-related intelligent software solutions.

Of those who are unemployed ($n = 4$), two alumni reported difficulty finding jobs due to a significant skill gap between their education and industry requirements, as well as a reluctance to hire non-EU or non-Dutch speaking graduates. Thus, finding the ideal combination of a work culture in the high-tech industry and the niche nature of robotics in the Netherlands presents challenges. Graduates may struggle to compete against specialists in software and mechanical engineering roles. The other two alumni were actively seeking specific positions and acknowledged that this process requires time.

Graduates expressed satisfaction with their first job, with 13 out of 14 (93%) answering 'Yes' to the questions: 'Does your current place of employment match the expectations you had for your first job at graduation?' and 'Does your current role match the expectations you had for your first job at graduation?' (Response options were: Yes, No). When asked in a free-response item about the parts of their career they enjoy the most, a common theme of working with robots and real-world systems emerged. Conversely, respondents were most disappointed with the high number of meetings, slow processes, and the necessity to adapt to the software and resources available within their organisation.

4.3 About the Programme

In response to the question of whether the MSc Robotics programme provides a comprehensive view of the field of Robotics, 83% (15 out of 18) of respondents affirmed this. In a follow-up free-response item, they cited the breadth of the program, from perception to dynamics to planning, as a key factor. However, some respondents felt the program lacked in certain areas such as hardware/systems engineering and control.

Furthermore, 94% (17 out of 18) would choose the Robotics programme again if given the chance. The reasons for this choice varied, with some citing their interest in the field of robotics and the focus on software in the programme. Others appreciated the opportunity to apply knowledge into practice. However, one respondent noted the difficulty in securing a job in the current tech industry recession. Similarly, 88% (15 out of 17) would recommend the programme to prospective MSc students. The reasons included its focus on software, good organisation, quality of teaching, and the opportunities it provides for personal development.

Furthermore, responses gave feedback on two points: what additional learning they would have liked from the program, and what new engineering courses they think should be included in the curriculum. Their main ideas were that they wanted more training in technical software, particularly for cloud-based and production environments. They also wished for more in-depth knowledge in systems engineering and mechatronics, a greater focus on how to integrate hardware, and stronger skills in control theory and the structure of machine learning pipelines.

When asked what personal development experience they would suggest adding to a future curriculum, key themes that emerged were a reduction in personal development courses, a focus on practical skills such as evaluating oneself for job interviews and understanding job requirements, and the importance of multicultural collaboration and awareness.

When asked about the most useful aspects of the programme, respondents cited the development of critical skills such as coding and problem-solving, the practical application of these skills in lab assignments and projects, and the comprehensive knowledge foundation provided by the program, particularly in areas such as machine learning, deep learning, and ROS (i.e., Robot Operating System, a widely used open-source framework for building and managing robot software). Conversely, when asked about the least useful aspects of the programme, two courses emerged: Robot and Society (n = 6) and Portfolio (n = 5). On the other hand, one respondent remarked that he loved the reflective engineering concept of the programme.

Four out of 16 respondents (25%) reported having completed the programme in 24 months or less, while the remaining 12 (75%) reported 25–30 months. Inquiries about which parts of the MSc Robotics programme took longer than the nominal duration yielded the following responses: the thesis project (n = 11), the literature study (n = 4), combining study with other activities (n = 4), and the internship (n = 3). This is in line with earlier results of an internal survey that indicated that a primary reason for study delay involved a conscious decision by the student.

Finally, in response to the question regarding gender, all 16 respondents identified as male. When asked about the location of their Bachelor degree, the majority (56%) completed their degree at TU Delft. 38% completed their degree outside the EU, while 6% completed their degree elsewhere in the Netherlands.

5 FINAL REMARKS

In summary, the findings about the new Robotics programme are favourable, and the feedback from students, graduates, industry representatives, and the faculty provides opportunities for continuous programme development. It remains to be seen whether the modifications to the Vision and Reflection course will yield positive outcomes. A more in-depth evaluation of this component is needed. Additionally, further investigation and analysis are required to address the delays within the programme and the unpopularity of the ethics course. It is important to note that the alumni survey results are based on only half of the cohort. All of these respondents completed their degree within 2.5 years and are likely the more successful portion of the cohort. Consequently, it is essential to monitor the progress of the portion of the cohort that requires more time to graduate.

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APPENDIX A: FINAL QUALIFICATIONS OF THE MSC ROBOTICS

1. Competent in the scientific discipline Robotics
A graduate in Robotics is able to…
1A. …acquire and apply broad knowledge on Robotics on the multidisciplinary intersection of mechanical engineering, Robotics and artificial intelligence, more particularly in dynamics, system identification, modelling, control, machine learning, machine perception and human-robot interaction.
1B. …model, design and control robotic systems.
1C. …analyse, evaluate and validate robotic systems in complex environments.
1D. …relate scientific knowledge to robotic systems, critically considering their interaction with societal aspects.
2. Competent in doing research
A graduate in Robotics is able to…
2A. …study a topic by critically selecting relevant scientific literature.
2B. …generate innovative contributions in developing intelligent machines.
2C. …write a scientific report about own research.
2D. …measure, model, and explain the interaction between humans and intelligent machines.
3. Competent in designing
A graduate in Robotics is able to…
3A. …develop mathematical and physical systems using state-of-the-art knowledge.
3B. …translate complex multidisciplinary research to working robotic designs.
3C. …design algorithms and software for complex robots.
3D. …design interfaces for human interaction so that a robotic system's functionality can be understood, taught and corrected by users.
3E. ….design robotic systems which can move safely and efficiently in human-inhabited environments.
4. A scientific approach
A graduate in Robotics is able to…
4A ….contribute novel techniques on the intersection between mechanical engineering, systems and control, and artificial intelligence.
4B. …analyse and design multidisciplinary solutions using system identification, modelling, and simulation.
4C. …solve technological problems in a changing environment, considering ethics, safety, ambiguity, incompleteness and limitations.
4D. …effectively lead, co-create and collaborate with a research team.
4E. …design and perform experiments to compare, investigate, evaluate and test different robotic solutions across disciplines.
5. Basic intellectual skills
A graduate in Robotics is able to…
5A. …develop a vision for applying robotics to address industrial and societal needs.
5B. …consider the design of robotic systems from economic, social, cultural and ethical perspectives.
5C. …critically reflect on own role in projects, in relationship to that of others.
5D. …remain professionally competent with an eye for the needs in the field.
6. Competent in operating and communicating
A graduate in Robotics is able to…
6A. …work both independently as well as in a multidisciplinary team
6B. …operate and communicate in a responsible, ethical and transparent manner, with an open-minded attitude.
6C. …explain and defend research activities and outcomes to academia and industry, both specialists and non-specialists.
6D. …understand and explain robotic systems in relation to other fields.
6E. ...advise on technical steps towards integral robotic solutions in complex environments.
7. Considering the temporal and social context
A graduate in Robotics is able to…
7A.… consider the limitations and possibilities of applying robotics to solving safe technological and societal problems.
7B. …evaluate and assess the technological, ethical and societal impact of one's work.
7C. …act with vision in an interconnected and rapidly changing world.
7D. …act with integrity and responsibility regarding sustainability, safety and privacy, and economic and social wellbeing.